EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN – A&B DEPARTMENT

CERN-AB-2006-041

CLIC-Note-675

CTF3-Note-073

Commissioning Status of the CTF3 Delay Loop

R. Corsini, D. Alesini[1], C. Biscari[1], B. Buonomo[1], S. Döbert, A. Ghigo[1],
F. Marcellini[1], B. Preger[1], M. Serio[1], A. Stella[1], F. Tecker, P. Urschütz
CERN, Geneva, Switzerland

The CLIC Test Facility CTF3, built at CERN by an international collaboration, aims at demonstrating the linear collider by 2010. In particular, one of the main goals is to study the generation of high-current electron pulses by interleaving bunch trains in delay lines and rings using transverse RF deflectors. This will be done in the 42 m long delay loop, built under the responsibility of INFN/LNF, and the 84 m long combiner ring that will follow it. The delay loop installation was completed and its commissioning started at the end of 2005. In this paper the commissioning results are presented, including the first tests of beam recombination.

1) INFN-LNF, Frascati, Italy

Presented at
EPAC'06, Edinburgh, UK,
June 26-30, 2006

Geneva, Switzerland
June 2006

COMMISSIONING STATUS OF THE CTF3 DELAY LOOP

R. Corsini, S. Döbert, F. Tecker, P. Urschütz, CERN, Geneva, Switzerland
D. Alesini, C. Biscari, B. Buonomo, A. Ghigo, F. Marcellini, B. Preger, M. Serio, A. Stella, INFN/LNF, Frascati, Italy

Abstract

The CLIC Test Facility CTF3, built at CERN by an international collaboration, aims at demonstrating the feasibility of the CLIC scheme of multi-TeV electron-positron linear collider by 2010. In particular, one of the main goals is to study the generation of high-current electron pulses by interleaving bunch trains in delay lines and rings using transverse RF deflectors. This will be done in the 42 m long delay loop, built under the responsibility of INFN/LNF, and the 84 m long combiner ring that will follow it. The delay loop installation was completed and its commissioning started at the end of 2005. In this paper the commissioning results are presented, including the first tests of beam recombination.

INTRODUCTION

The aim of the CLIC (Compact Linear Collider) Study is to investigate the feasibility of a high luminosity, multi-TeV linear e+ e- collider [1]. In order to limit the total length, CLIC employs normal-conducting accelerating structures operating at a very high gradient (150 MV/m), and powered by 30 GHz RF pulses with a peak power of 150 MW. Since conventional RF sources cannot provide such pulses, CLIC is based upon a two-beam-acceleration concept [2], in which a high current electron beam (drive beam) runs parallel to the main beam and is decelerated to produce the RF power. The generation of the high-intensity drive beam pulses with the right time structure is one of the main challenges in CLIC. Initially, a long pulse is accelerated using a low frequency normal-conducting linac. Funnelling techniques in delay lines and rings are then used to give the beam the desired structure while increasing its intensity. In this process the electron bunches are interleaved by the use of transverse RF deflectors. The bunch spacing is thus reduced and the beam current is increased.

It is generally accepted that CLIC technology is the only path to multi-TeV colliders. However, several critical issues still need to be addressed. The experimental program of the new CLIC Test Facility (CTF3) tackles the main issues, i.e., the generation and use of the drive beam and the testing of 30 GHz structures and components, with the goal of demonstrating the CLIC feasibility before 2010, when the first LHC results should be available.

CTF3 [3] is presently being built and commissioned at CERN by an international collaboration, including Ankara and Gazi Universities (Turkey), BINP (Novosibirsk), Helsinki Institute of Physics, IAP (Nizhny Novgorod), CIEMAT (Spain), DAPNIA (Saclay), Finnish industry, INFN-LNF (Frascati), JINR (Dubna), LAL (Orsay), North-Western University of Illinois, RAL (Oxford), SLAC (Stanford) and Uppsala University (Sweden).

The facility is located in the buildings of the former LEP pre-injector complex, whose hardware is partly re-used, and is designed to work at a lower beam current and a lower energy than the CLIC drive beam (3.5 A instead of 5.7 A and 150 MeV instead of 2.4 GeV). In its final configuration it will include a 70 m long drive-beam linac followed by two rings, where the beam manipulations will be carried out: a 42 m delay loop and an 84 m combiner ring. After such manipulations the drive beam will have a current of 35 A and will be transported to an experimental area to produce 30 GHz RF power for structure tests. In the same area, another linac will provide a main beam for a CLIC two-beam module [4] and a test decelerator will be used for drive beam stability studies [5]. CTF3 also has a second 30 GHz RF power station (halfway along the linac) working at a lower drive beam current.

In 2003-2004 the injector, linac, the mid-linac power station and an end-of-linac magnetic chicane with variable momentum compaction were installed and commissioned. The installation of the delay loop, under full responsibility of INFN-LNF, was completed during 2005 (see Fig. 1). The loop has a two-fold symmetry, with double injection/extraction septa, 10 bending magnets and 10 independent quadrupole families. It includes an RF deflector used for injection (as described later) and a wiggler employed to tune its path length. INFN provided sextupoles, correctors, the wiggler, the vacuum system, the 1.5 GHz RF deflector, waveguides and some beam diagnostics. CERN provided the dipoles, quadrupoles, power converters, the septa, controls, the 1.5 GHz RF system, vacuum pumps and infrastructure (cabling, alignment, water, installation support).

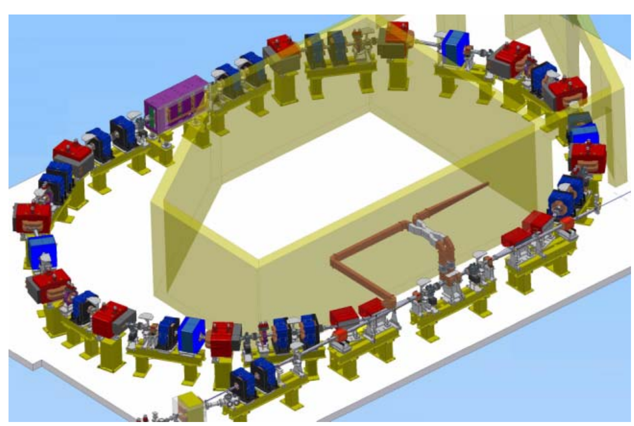

Figure 1: Delay loop layout. The beam comes from the bottom left corner. Septa and dipoles are red, quadrupoles appear in blue. Also visible are the waveguide network feeding the deflector (bottom right) and, on the opposite side, the wiggler (violet).

THE RECOMBINATION PROCESS

The role of the delay loop in CTF3 is to sub-divide the 3.5 A, 1.4 μs long beam-pulse accelerated in the drive-beam linac into five 140 ns long pulses, separated by 140 ns "holes", increasing at the same time both the initial current and the bunch repetition frequency by a factor 2.

The procedure is schematized in Fig. 2 and described in the following. The incoming pulse is composed by ten 140 ns long sub-pulses, in which bunches occupy either even or odd 3 GHz RF buckets. Such time structure is obtained in the injector, where three sub-harmonic buncher (SHB) cavities at 1.5 GHz are followed by a 3 GHz bunching system composed of a single-cell standing-wave pre-buncher and a graded-β travelling-wave buncher. The sub-harmonic cavities and their sources are wide-band systems and allow a fast switching of the RF by 180° [4]. When they are powered, only one every second 3 GHz buckets is populated (apart from a small fraction of the charge, captured in parasitic "satellite" bunches). The sub-pulses can then be easily "phase coded", putting the main bunches in odd or even buckets. The phase switch can be repeated several times as needed and is very fast, of the order of 5-6 ns [4]. A transverse RF deflector working at 1.5 GHz sends the first sub-pulse (labelled as even RF buckets in the figure) into the delay loop. The loop length of 42 m corresponds to the sub-pulse length of 140 ns, thus the "even" bunches are coming back at the deflector at the same time as the "odd" bunches of the next sub-pulse from the linac. The delay loop length is precisely tuned to be an integer number of the RF wavelength, therefore odd and even bunches arrive with opposite phases and receive opposite kicks.

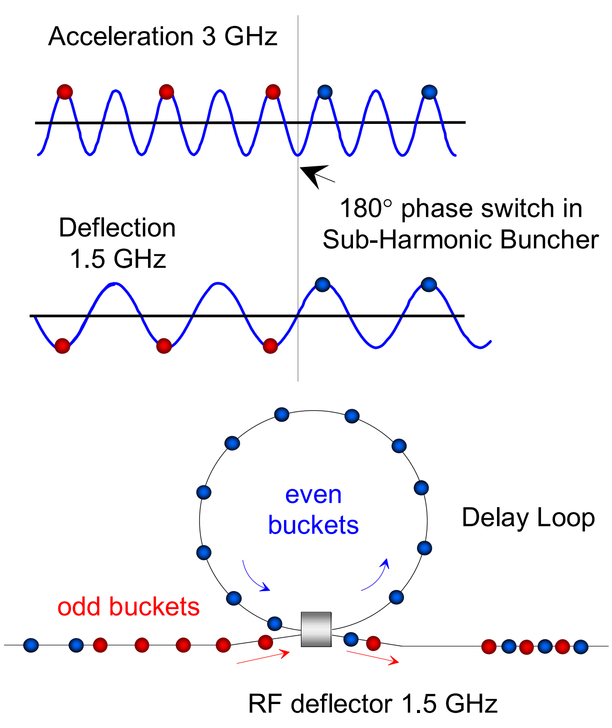

Figure 2: Schematic of the delay loop recombination.

However, since their incoming angles are also opposite, they are interleaved and combined into the same orbit. The process also naturally produces a gap of 140 ns, which is essential for clean extraction by a kicker in the next combiner ring stage. The bunch spacing is now 10 cm and the current of the train is doubled.

It should be noted that, in alternative of the RF deflector, two small horizontal dipoles located close to it can be used to kick the beam in and out of the delay loop. Of course in such a magnetic injection configuration (essentially used for setting-up during commissioning), the whole beam is sent either around the loop or straight past it and no re-combination is possible.

DELAY LOOP COMMISSIONING

The 2005 run

Beam commissioning of the delay loop started in November 2005. The beam-time available was only about 3 weeks and operation was hampered by the fact that, due to delays in the delivery of components, only one SHB cavity out of three and 6 beam position monitors (BPM) out of 17 were available. In spite of that, a circulating beam was obtained in a very short time, first using magnetic injection, as described above, and then RF injection. The delay loop optics used was relaxed with respect to the nominal isochronous one, which implies relative strong focusing. Initially the SHB system was turned off, and the beam was bunched at 3 GHz, but in the last few days of the run the one available SHB cavity was put in operation, together with the fast phase switch control, and a first re-combination test could be performed. Beam current and pulse length in the linac were limited in this period to less than 1 A and 300 ns for radiation safety, in order to allow access during operation to the klystron gallery located on top of the building, even in case of large losses in the delay loop. Therefore the re-combination yielded a single 140 ns pulse, with slightly more than 1 A beam current. During these tests, a detailed setting-up procedure was developed and validated, starting with magnetic injection and following several steps to determine experimentally the optimum power and phase in the RF deflector. A bunch length measurement test using the same deflector was also performed. In such a test, the beam was sent straight past the delay loop using the small dipoles, and the RF deflector was powered and phased such that the beam arrived at the RF zero crossing. The head and the tail of each bunch were then kicked in opposite directions, and the subsequent increase of the beam size, observed in a downstream optical transition screen, was used to determine the bunch length, showing a resolution of the order of a picosecond.

The 2006 run

Commissioning continued from March to May 2006, for a total of about 8 weeks. In the meanwhile, two additional BPMs were installed. Current and pulse length were not limited any more, since access to the klystron gallery was controlled, and the nominal values (3.5 A, 1.5 µs) were used in the linac, for a final momentum of 100 MeV/c. The nominal isochronous optics was implemented in the delay loop, and the available beam-time was sufficient to perform systematic optics measurements. Transverse beam properties (emittance and Twiss parameters) at the entrance of the delay loop were determined through quadrupole scans [5], and the dispersion function at the position of the delay loop BPMs was measured as well. This was done by scaling up and down the current of all delay loop magnets and recording the corresponding beam position. The orbit difference, normalized to the relative magnet scaling, is then equal to the dispersion function. Such a measurement was indeed very useful, since a comparison with the model of the first data allowed to identify a calibration error of about 20 % in three quadrupole families. Once the calibration was corrected, a reasonable agreement was found (see Fig. 3). The slight asymmetry in the model prediction reflects a small energy mismatch, identified after the measurement.

As mentioned before, the beam time-of-flight in the delay loop must be precisely equal to an integer number of RF deflector periods. The delay loop wiggler is indeed used to tune the path length accordingly. This is done experimentally as follows: the beam is sent straight past the loop and its phase measured using an RF pick-up, in which the beam induced signal at 3 GHz is mixed with a reference. The beam is then sent around the loop, with the wiggler off. The phase difference is measured, the wiggler is turned on and its current adjusted. A phase difference of 10° (5° at 1.5 GHz) was measured with the wiggler off and compensated with a wiggler current of about 50 A.

Synchrotron light ports built in the vacuum chambers of two dipoles were used, together with a streak camera, to check the beam time structure. The bunch length was also measured for two different settings of the upstream chicane. The measured values (σ_Z = 4.5 and 9 ps for momentum compaction R_{56} = 0.22 and 0.45, respectively),

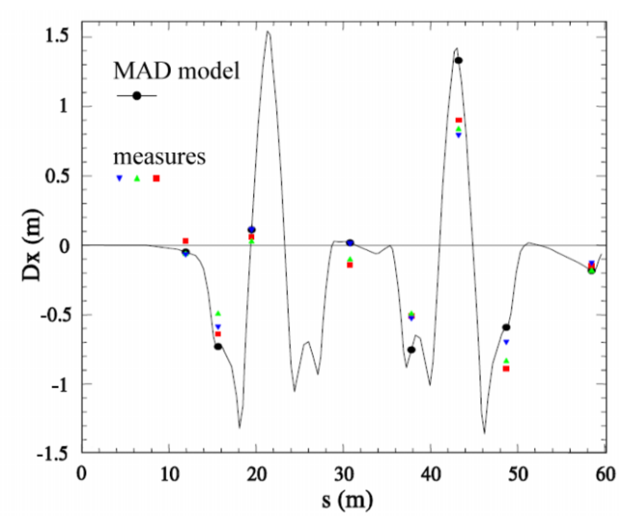

Figure 3: Values of the horizontal dispersion function at 8 BPMs inside and around the delay loop, obtained from three measurements (coloured symbols) and compared with the MAD model prediction (line with black dots).

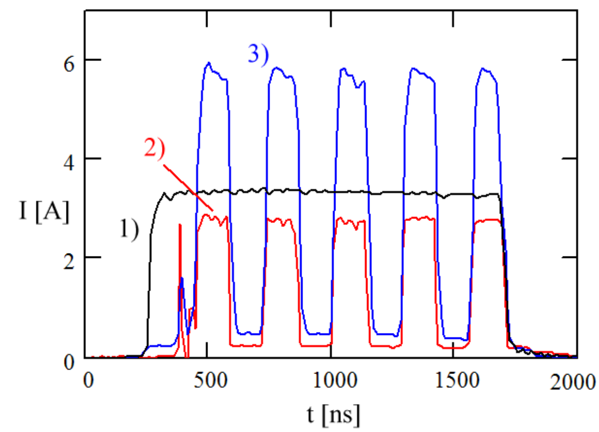

Figure 4: Beam current as a function of time, measured: 1) before the delay loop 2) in the loop 3) after the loop, showing the final recombination in five 140 ns pulses.

were consistent with expectations.

The final beam re-combination is shown in Fig. 4. The 1.5 µs, 3.3 A incoming pulse is converted in a series of five 140 ns pulses with a current of 5.8 A. About 8.5 % of the initial current is contained in “satellite” bunches, as expected from simulations [4]. This fraction of the beam is not combined in the main pulses, as shown in Fig. 4, where it can be seen in the space between them.

CONCLUSIONS

The CTF3 delay loop commissioning started in November 2005 and has been essentially completed in May 2006, when a recombination of five 140 ns long pulses with a current close to the nominal value was successfully obtained. Several beam dynamics and optics measurements were performed, in good agreement with simulations. Further studies will take place in the next running period, to confirm and extend the first data.

REFERENCES

[1] G. Guignard (Ed.), “A 3 TeV e+e- linear collider based on CLIC technology”, CERN 2000-008, 2000.

[2] R. Corsini (Ed.), “The CLIC RF power source”, CERN 99-06, 1999.

[3] G. Geschonke and A. Ghigo Eds, “CTF3 Design Report”, CERN/PS 2002-008 (RF).

[4] T. Ekelöf, M. Johnson, V. Ziemann, H. Braun, S. Döbert, G. Geschonke, J. Sladen, W. Wuensch, “The Two-Beam Test-Stand in CTF3”, these Proceedings.

[5] S. Döbert, G. Rumolo, D. Schulte, I. Syratchev, D. Carrillo, “Progress on the CTF3 Test Beam Line”, these Proceedings.

[6] P. Urschütz, H. Braun, R. Corsini, S. Döbert, T. Lefevre, G. McMonagle, J. Mourier, J. Sladen, F. Tecker, L.Thorndahl, C. Welsch, “Beam Dynamics and First Operation of the Sub-Harmonic Bunching System in the CTF3 Injector”, these Proceedings.

[7] P. Urschütz, H. Braun, R. Corsini, S. Döbert, F. Tecker, A. Ferrari, “Beam Dynamics Studies and Emittance optimization in the CTF3 Linac at CERN”, these Proceedings.